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ALTERNATIVES FOR RESTORATION OF ESTUARINE HABITAT AT THE MOUTH OF REDWOOD CREEK, HUMBOLDT COUNTY, CALIFORNIA

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Abstract. Aggradation at the mouth of Redwood Creek has resulted in loss of productive estuarine and slough habitat throughout most of the year. At present, the timing of juvenile salmonid migration does not correspond with high invertebrate productivity which is dependent on estuarine conditions, substrate stability, and algae growth. During low flows, the sloughs are usually inaccessible to migrating salmonids. Aggradation of the sloughs has resulted from construction of flood control levees completed in 1968 and is compounded by the large upstream contribution of sediment. Rehabilitation alternatives include restoration of the natural circulation pattern, sediment removal, and control of water level.

INTRODUCTION

The mouth of Redwood Creek is located approximately 4.0 river km west of Orick, California. The relatively narrow floodplain is periodically inundated due to steep basin gradients, intense storms and rapid runoff characteristic of the region. The series of damaging floods in 1950, 1953, 1955, and 1964 prompted channelization of Redwood Creek in the vicinity of Orick. The downstream portion of the levee bypasses the last meander and diverts the flow directly to the ocean. Deleterious effects of restructuring the channel include loss of riparian vegetation, accumulation of sediment in areas which were previously viable fish-rearing habitat and isolation of productive slough areas.

The anadromous fishery of the Redwood Creek watershed has experienced a substantial reduction which is documented for the last 15 years by records available from Humboldt County Prairie Creek Fish Hatchery (Sanders, personal communication). Part of this decline is related to the degradation of salmon spawning and rearing habitat in the Redwood Creek basin. However, alteration of the estuarine environment has also adversely affected the fishery. The estuary serves as a transition zone between freshwater and saltwater environments and plays a crucial role in the lives of adult and juvenile salmonids.

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In order to gain a better understanding of existing estuarine productivity and governing physical processes, physical and biological studies were initiated at the mouth of Redwood Creek. These studies included water quality monitoring; determination of seasonal patterns of distribution and use by anadromous salmonids; determination of types and relative abundance of fish food organisms; and determination of historic and present patterns of inundation, sediment accumulation, flow, and general estuarine morphology. Such information is prerequisite to considering the feasibility of developing rehabilitation alternatives for the estuary. It also provides baseline data which will be used to evaluate the effectiveness of rehabilitation efforts.

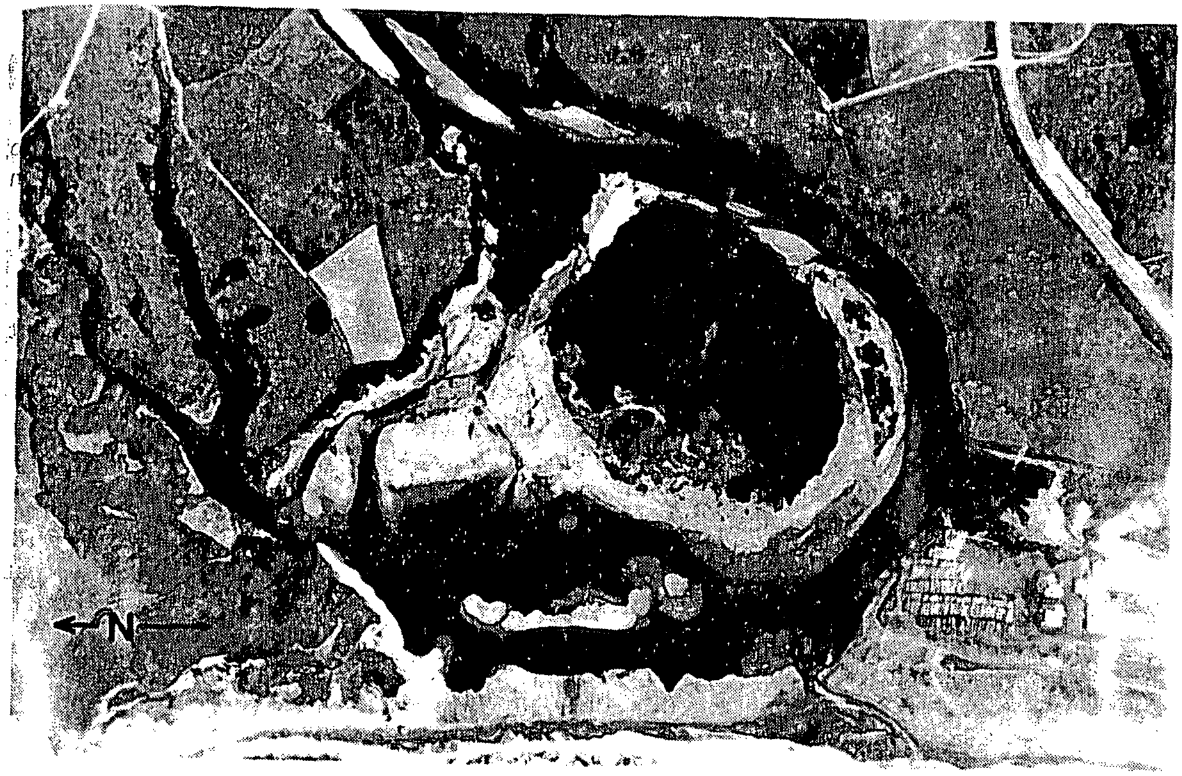
HISTORIC CHANGES IN MORPHOLOGY

The original channel of Redwood Creek meandered to the south, turning to create an eddy against the north cliffs (Figure 1). Local residents indicate the water depth was at least 20 feet in this area before levee construction. Sediment was deposited extensively across the floodplain during overbank floods but the channel areas were scoured. The infamous December, 1964 flood removed the entire beach from near the north cliffs to the Cal Pacific mill site. The abandoned channel on the north side of the floodplain (north slough) and the middle overflow channel were also flushed periodically.

Following the December, 1964 flood the Army Corps of Engineers finalized channelization plans for the lower 5.3 km reach of Redwood Creek. Construction of the levees was completed in September, 1968 (Figure 2). The direct and immediate effects included removal of riparian vegetation, destruction of pools and riffles, increased channel gradient, decreased substrate stability and alteration of the circulation pattern. Loss of circulation in the last meander created a south slough and the main flow was confined to a straight exit.

Other effects developed cumulatively, resulting from natural marine sedimentation interacting with the changed fluvial system. Tidal currents, overwash, and dispersal of river-borne sediment have filled (aggraded) the neck of the south slough by 3-4 m. Aggradation has resulted in isolation of the two sloughs and loss of access to the only undisturbed habitat remaining at the mouth.

The crest of the sand spit or berm has grown by 1.4 - 1.8 m since the 1964 Army Corps survey. This barrier prevents saltwater intrusion by overwash across most of the spit. Estuarine conditions develop only following periods of high ocean swells in late summer or early fall when saltwater enters through the mouth outlet or washes over the low berm on the north side. According to Pritchard (1967), an estuary is a semi-enclosed body of water which has a free connection with the open sea and within which sea water is measurably diluted with freshwater. Prior to channelization, more opportunity existed for a free connection between the ocean and embayment (Figure 1). The lower berm, lower channel gradient, and deep water area near the north cliffs suggest that historically there was considerable saltwater intrusion and estuarine conditions were prevalent. Thus, the levees have altered circulation such that presently no true estuary exists at the mouth of Redwood Creek.



'igure 1. Mouth of Redwood Creek in August, 1962, showing original channel with ieander. Note outlet position on south side of the beach.

'igure 2. Mouth of Redwood Creek in May, 1978, showing flood control levees vhich were completed in October, 1968. Note sediment accumulation in the iecks of the north and south sloughs.

SEASONAL CHANGES IN MORPHOLOGY

It is important to consider short-term or seasonal variations when comparing historic photographs and surveys with the present mouth configuration. Changing fluvial discharge and wave climate determine the seasonal progression of mouth morphology. High winter flows scour a channel which exits along the rocky north side of the beach. The north and south sloughs are connected to the main channel during high discharge.

In the spring, decreasing discharge allows waves at high tide to diffract around the south margin of the outlet. Waves deposit a lobe of sand on the back side of the berm which builds into the deep water embayment. Summer swell waves build up the beach face also. Under certain conditions this may be accompanied by migration of the creek outlet to the south. Longshore currents are produced by prevailing north-northwest winds. When high swells are actively transporting sand, these currents are effective in driving the longshore drift to the south. Migration progresses episodically and rapidly during conditions of north winds and swells. Waves deflect the channel against the southeast bank of the outlet, eroding the bank while depositing a sill on the northwest side. Wave swash (overwash) also aggrades the channel bed, raising it above the previous level. This process restricts the rate of outflow and results in the formation of a large embayment when rates of outflow, seepage, and evaporation are less than inflow. Continued wave swash may close the outlet and extend the berm further into the embayment. With expansion of the embayment, the south slough becomes connected when water levels exceed 1.1 m. The north slough remains inaccessible until water reaches the 1.2 m level.

Frequent slough flooding is a relatively recent problem as evidenced by the encroachment of rushes (Juncus) onto pasture lands. The highest backup of water ever observed by local residents occurred in January, 1981, just before the berm was eroded naturally. This problem may be due to aggradation in the slough areas and a higher berm. Also, the rate of seepage through the berm may be less than in the past. This could result from a shift to smaller sizes of sediment being transported from the Redwood Creek basin later in the year. High water levels induce local ranchers to breach the sand berm prematurely, sending fish and invertebrate fauna out to sea.

INVERTEBRATE PRODUCTIVITY

Redwood Creek, from the Highway 101 bridge to the mouth, can be characterized as "macrobenthically" poor. Low productivity from November through July, 1980, overlapped periods of peak downstream migration of juvenile chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (Salmo gairdneri). The sloughs appear to support greater invertebrate production throughout the year. Although not showing any significantly greater diversity than the creek, the sloughs (especially the south slough) seem to provide for large biomass. This secondary production is limited to the margins and shallow portions of the sloughs. Hester-Dendy multiple plate sampling results indicated that organisms are not found in or on the substrate of the deep waters of the sloughs at least during late summer through early fall. It is not known whether this is a reponse to some limiting factor, though oxygen tensions are minimal to nonexistant in these "amacrobenthic" areas.

During the benthos sampling periods, there was an exeception to the poor secondary production of the lower creek. This was the appearance of extensive populations of the amphipod *Corophium*. These tube-building detritivores attained biomass levels that may be as high as any in the Redwood Creek watershed (13.4 g dry wt/m^2). The factors responsible for this crustacean bloom seemed to be linked with benthos stabilization and primary production of the filamentous algae, *Cladocera*. High winter and spring flows keep the substrate in constant motion. Once high creek flows have subsided, the capacity to transport material is diminished, and a stable substrate is created. In late June, 1980, an enclosed embayment became contiguous with both sloughs. This coincided with the reproductive cycle of the two species of *Corophium*. *Corophium salmonis*, which prefers a finer silty-mud substrate, and *C. spinicorne*, which tolerates a coarser sand substrate, established mixed populations within the new habitat (McCarthy, 1972). Unfortunately, the embayment was drained July 2, 1980 before any extensive sampling could be performed. However, within a month of the breaching, the embayment was reestablished and the macrobenthos was monitored. *C. spinicorne* dominated the populations upstream from the end of the levees, achieving a maximal biomass of 11.35 g dry wt/m^2. Mixed *Corophium* populations in the embayment reached biomass levels ranging from 1.4 - 13.4 g dry wt/m^2, 1.4 - 12.7 g dry wt/m^2, and 0.8 - 4.8 g dry wt/m^2 for the dates August 22, September 22, and November 1, respectively. The decreasing biomass is more a result of the dominance of smaller immature amphipods than decreases in individuals within the populations.

It is not known where the individuals responsible for this population overwinter. Although both species are present in the sloughs throughout the year, some evidence indicates that individuals may overwinter within the creek by virtue of the stable substrate provided within the interstices of the rip rap levee.

Stomach analysis was performed to evaluate fish feeding habits. Of the stomach studied to date, 71% contained insect material, with dipterans being the primary food items (67% of all stomachs). The steelhead trout, which tended to be larger and older, fed heavily on both species of *Corophium* (found in 71% of trout stomachs vs. 0% in the stomachs of the smaller chinook). The prickly sculpin, *Cottus asper*, and starry flounder, *Platichthys stellatus*, two non-estuarine species commonly found in Redwood Creek, consumed only *Corophium*, suggesting a bottom feeding behavior.

Consistent production within the creek, beneficial for the growth and production of migrating juvenile salmonids, is lacking. This may be due to the absence of suitable habitat and nutrient sources for the invertebrate populations. The barren habitat of coarse sand and gravel between the levees contributes to low invertebrate diversity. Any attempt to introduce new and different habitats for the invertebrate forage species would be advantageous to an increased production that would be stable throughout the year. Unlike the sloughs which gain much of their nutrients from autochthonous as well as allochthonous sources, the creek invertebrates rely much of the year on debris transported from upstream. Management actions to renew riparian habitat along the sandbars within the levees might stimulate increased secondary production.

FISH HABITAT

Historically, salmon and steelhead runs were much greater than at present. Part of this decline can be attributed to alteration of the estuarine habitat.

The obvious role of the estuary for anadromous salmonids is as the passageway to the sea for downstream migrant juveniles and to the stream for upstream migrant adults. In addition to serving as an access point, the estuary is an area for acclimation from freshwater to saltwater or vice versa; and as an area generally rich in food, where substantial feeding and growth of juveniles may occur.

Reimers (1973) documented the role that estuaries play in fall chinook salmon production. From scale analysis of spawning fall chinook, Reimers determined that the majority of returning adults spend June, July, and August as juveniles within the estuary before completing their seaward migration. His investigation determined that juvenile chinook spending less than three months in the estuary seldom returned to spawn in the natal stream. Reimers concluded that these fish did not survive as well as the fish that had spent three months in the estuary. Although not as well documented, it has been shown that juvenile steelhead will spend rearing time in the estuary (Amend et al., 1980) while coho salmon (*Oncorhynchus kisutch*) appear to move into the sea almost immediately.

If an embayment forms during the peak migration of juvenile chinook salmon and steelhead, the juvenile salmonids will reside in this area for an extended period before entering the ocean, as was the case during the 1980 migration. The embayment formed in early June and the salmonid population began to increase indicating extended utilization of the area. The population was estimated at 20,000 salmonids on June 24, and the catch per unit effort (CPUE) was 200 fish per seine haul. These fish were free to migrate into the ocean, further indicating an affinity for the embayment. However, on July 2, the berm was breached by local ranchers because the embayment water threatened to flood their fields. The breaching released 75% of the water in embayment and caused juvenile salmonids to involuntarily enter the ocean. Sampling efforts following breaching showed a CPUE near zero, indicating a radically reduced population. The only fish caught were located near the outlet in one of the few remaining deep pockets of water. The juvenile salmonids appeared to be smolting (indicated by their silver appearance), before being flushed into the ocean, but to what degree the smoltification process had reached is not known. Wagner (1974) documented reduced survival and growth to salmonids involuntarily inducted into seawater before the fish smolted. Had the berm not been breached, the juvenile chinook and steelhead would have been afforded a period of improved growth before entering the ocean and, therefore, an increased chance of survival.

Man-induced breaching of the berm and the lack of adequate water depth within Redwood Creek also affects returning adult salmon and steelhead. Breaching the berm before the fall rains may induce adult salmonids to enter the shallow estuarine area and remain there because of insufficient flow for them to continue upstream migration. In this shallow area, the salmon and steelhead are very vulnerable to illegal fishing practices, which have been substantial in some years according to local accounts. Prior to levee construction, the deep water area adjacent to the rocky headland provided a protected holding area for adults, thus premature breaching of the berm was not as devastating to the salmonid population.

When the channel was redirected, much riparian and submerged habitat was lost. In the area of the south slough, a diverse habitat exists, i. e., trees overhanging the water, submerged logs, and a deep water area along the south bank. The south slough is generally isolated from the main creek and therefore usually unavailable to migrating salmonids except under high water conditions. During the main May and June, 1980 migration of juvenile chinook and steelhead, the south slough was accessible from the main creek only in late June. The migrating juveniles utilized the expanded habitat when it was accessible. Water quality parameters remained at acceptable levels throughout the year and were not a deterrent to usage by juvenile salmonids.

Habitat in the north slough is even less accessible for fish than in the south slough. Water quality is also a problem in the north slough. Anoxic conditions exist on the bottom because of poor circulation and accumulation of floating and submerged woody debris. This condition limits the growth of plants which could provide a substrate for invertebrate growth and cover for fish.

Conditions in the creek are substantially different from those in the north and south sloughs. The creek margins and banks are devoid of any vegetative cover. A filamentous algae bloom in the spring provides suitable habitat for invertebrates but is too dense to provide cover for migrating salmonids. Cover exists only when water levels are high, providing access to voids along the rock levee and protection afforded by increased water depth. During low water essentially no cover is available, subjecting the migrant fish to increased avian predation. Juvenile steelhead and chinook tend to congregate in the deeper water areas, generally adjacent to the south levee. Other areas within the lower creek between the levees are not utilized at low water levels except when an embayment forms.

REHABILITATION ALTERNATIVES

From an ecological perspective, the objective of rehabilitation at the mouth of Redwood Creek is to improve the quality of aquatic habitat. Alternatives range from relatively inexpensive, temporary measures to costly permanent projects which would be complicated by political and legal concerns. The options are listed in order of increasing effectiveness in the restoration of fish habitat. Although it would be desirable to restore the estuary to its pristine state, the effects of increased sediment input from upstream sources must be considered. Redwood National Park is monitoring the rate of recovery from damaging floods and poor land use practices that have occurred in the basin over the last 30 years. Until streamside landslides heal and stored sediment moves out of the system, the levees may function to direct sediment through the mouth area. However, restoration of the natural circulation pattern and removal of large sediment accumulations at the mouth are necessary to increase the productivity of the estuary. Reestablishment of estuarine conditions with intrusion of nutrient-rich saltwater is also desirable.

Dredging

Dredging the embayment to historical depth would increase the amount of habitat available to juvenile and adult salmonids; allowing access to both the north and south sloughs and creating a deep pool near the neck of the north slough. The deep pool near the north slough might become a bi-layered estuarine system providing an area for acclimation to seawater by juvenile salmonids which they lack at present.

Dredging would only be a temporary solution depending on the rate of resedimentation. Ideally, dredging should be used in conjunction with restoration of historical circulation patterns to speed a return to pristine conditions.

Controlling the Embayment Water Level

Controlling the water level in the embayment would prevent the summer flooding of local pastures and would also help maintain some of the limited habitat. If the water level was maintained at a high enough level, the south slough would remain connected to the main channel, significantly increasing the habitat available to migrating fish.

By manipulating the length of the outlet, the embayment water level could be controlled. As the mouth migrates further south and the length of the outlet increases, the berms gets higher and the water level in the embayment increases. This migration reduces the flow gradient, decreases the water velocity and the amount of downcutting, and allows the berm to build higher. By reducing the length of the outlet, the channel gradient and water velocity would increase, resulting in downcutting through the berm and reduction of the water level in the embayment. Downcutting would be controlled by shortening the outlet gradually. This would allow time to evaluate the effect of each shortening and maintain an optimum embayment water level.

Circulation Through the Sloughs

Sediment in the necks of the north and south sloughs could be eroded naturally by diversion of sufficient flow through the sloughs. Pumping water from the main channel into the sloughs would not involve alterations of the levees, but would be costly in the long run. The natural force of high flows in Redwood Creek could be harnessed by constructing a spillway through the levee to the south slough (Figure 3). Another advantage to this alternative is that the amount of sediment delivered to the south slough could be regulated by the height of the spillway. Circulation could be enhanced by installing a culvert(s) in the north levee to deliver water into the drainage ditch that enters the south finger of the north slough. Properly designed, improvements would not result in loss of flood control as the levees would continue to contain high flows within the channel.

Partial Levee Removal

One alternative in the attempt to return the creek to its natural state would be the removal of the lower 1 km of the south levee (Figure 3). This rehabilitation alternative would allow the south slough to return to its status as a meander of the main creek. The result would be scouring of sand at the entrance, and an increase in the habitat accessible to migrating salmonids. Also, removal of that portion of the levee would allow dissipation of discharge over a widening area and thus create more stable substrates and areas for riparian habitats to develop, resulting in the enhancement of secondary production. Annual flooding of pasture lands resulting from levee removal could prove beneficial to soil fertility.

Removal of the lower 1 km of both levees would be similar in expected benefits to the previous option, and carry potential rehabilitation effects into the north slough. This alternative provides for both flood control for the town of Orick and the restoration of historical estuarine circulation patterns.

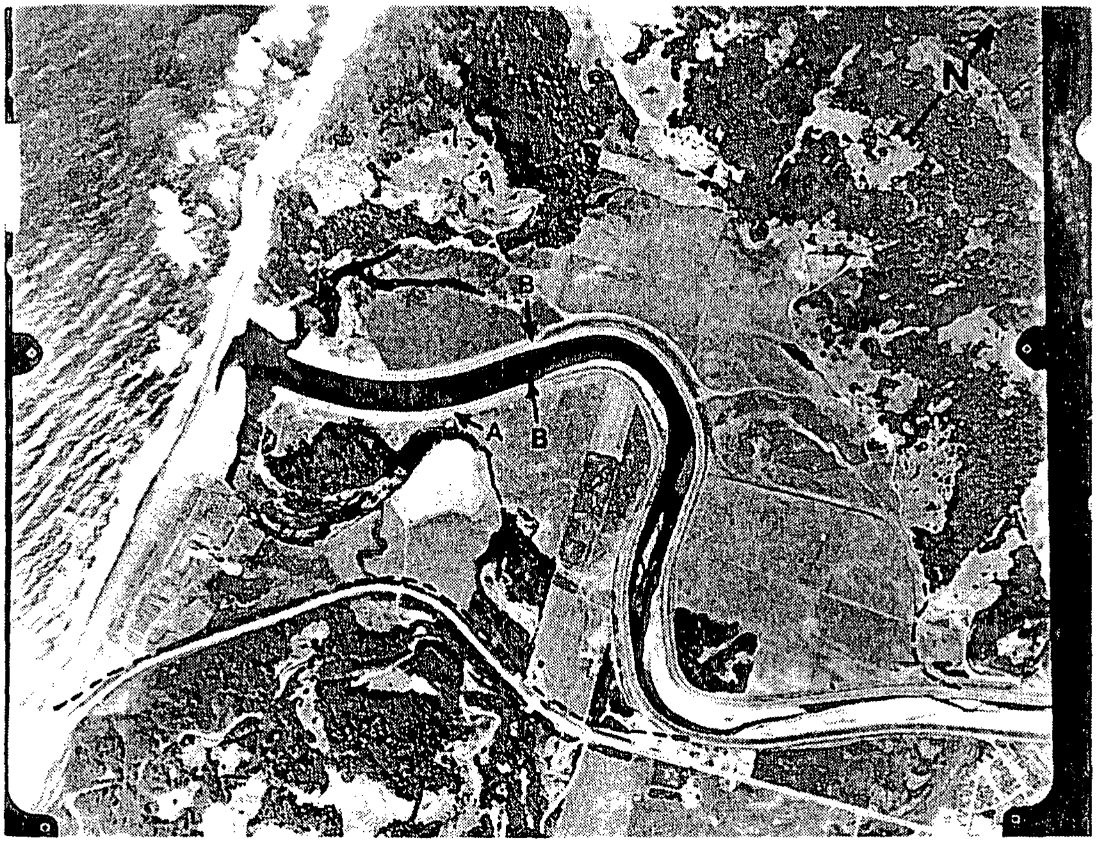


Figure 3. Redwood Creek showing the points of proposed options for restoration: levee spillway, (A); partial levee removal, (B); levee relocation, (Dashed line).

Relocation of the Levees

This alternative would be similar to partial removal of the levees except more of the lower creek would be returned to a natural condition. The levees would be rerouted at the first large meander west of Orick along Highway 101 (Figure 3). The county dump and pasture land might be subject to flooding on the south side. The levee could be rerouted on the north side to follow Hufford Road until it reached the hillslide near the mouth. Hufford Road could be relocated along the top of the levee to reduce the amount of land consumed by levee construction. Only pasture land on the north side of the creek would be exposed to flooding. Flood waters would flush away wastes and deposit nutrient-rich silt on the pasture lands. The benefits to terrestrial and aquatic wildlife would be similar to partial removal of the levees except more riparian habitat would be available.

CONCLUSION

The success of rehabilitation efforts depends on the cooperation of many agencies and individuals having regulatory or ownership interests at or near the mouth of Redwood Creek. Redwood National Park manages a quarter-mile strip of the coast. Humboldt County controls the levee and intertidal zone while private inholders own grazing land and forest near the mouth. The California Department of Fish and Game, Coastal Commission and U. S. Army Corps of Engineers will also be involved in management decisions. Flood control will continue to be a major concern. High flows which, in the past, flushed the north and south sloughs also affected some residents. Many would prefer not to repeat the experience. Thus, alternatives for restoration of estuarine habitat will be discussed by many people, hopefully with the unifying goal of fisheries enhancement.

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